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BANDWIDTH REQUIREMENTS FOR THE ADVANCED AMPHIBIOUS ASSAULT VEHICLE (AAAV) COMMAND VARIANT

by

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BANDWIDTH REQUIREMENTS FOR THE ADVANCED AMPHIBIOUS ASSAULT VEHICLE (AAAV) COMMAND VARIANT

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Submitted in partial fulfillment of the
requirements for the degree of

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I. INTRODUCTION

A. BACKGROUND

The Advanced Amphibious Assault Vehicle program is a major defense acquisition program undertaken by the Marine Corps to provide an amphibious family of vehicles consisting of personnel variants (AAAVP), command and control variants (AAAVC), and other dedicated mission role variants that may be required at a future date. The vehicles will use common subsystems/components to the maximum practical extent. The AAAV family will replace the current Assault Amphibious Vehicle (AAV7A1) family. The AAV7 was first fielded in 1972, underwent a major service life extension program in 1983-86, a product improvement program in 1986-91, and an upgrade and rebuild in 1999. The design will be over 30 years old when the AAAV is fielded. [Ref. 1] The AAAV supports theories first derived in the concept paper "Operational Maneuver From the Sea" (OMFTS). The tactical implementation of this concept is further detailed in "Ship to Objective Maneuver" (STOM). STOM describes the tactical implementation of OMFTS through the application of the tenets of maneuver warfare to amphibious operations. It builds upon many of the themes introduced in OMFTS such as use of the sea as maneuver space, sea basing, and elimination of the requirement for a traditional beachhead. Departing from the traditional, linear form of amphibious operations practiced during most of the 20th century, STOM envisions amphibious assaults in which both surface and vertical lift platforms launch from over-the-horizon (OTH) attack positions. (Figure 1) The concept calls for exploitation of navigation and information sharing technologies to allow landing force tactical commanders to control the maneuver of their units from the moment they cross the line of departure at sea, to arrival at the objective. [Ref. 1]

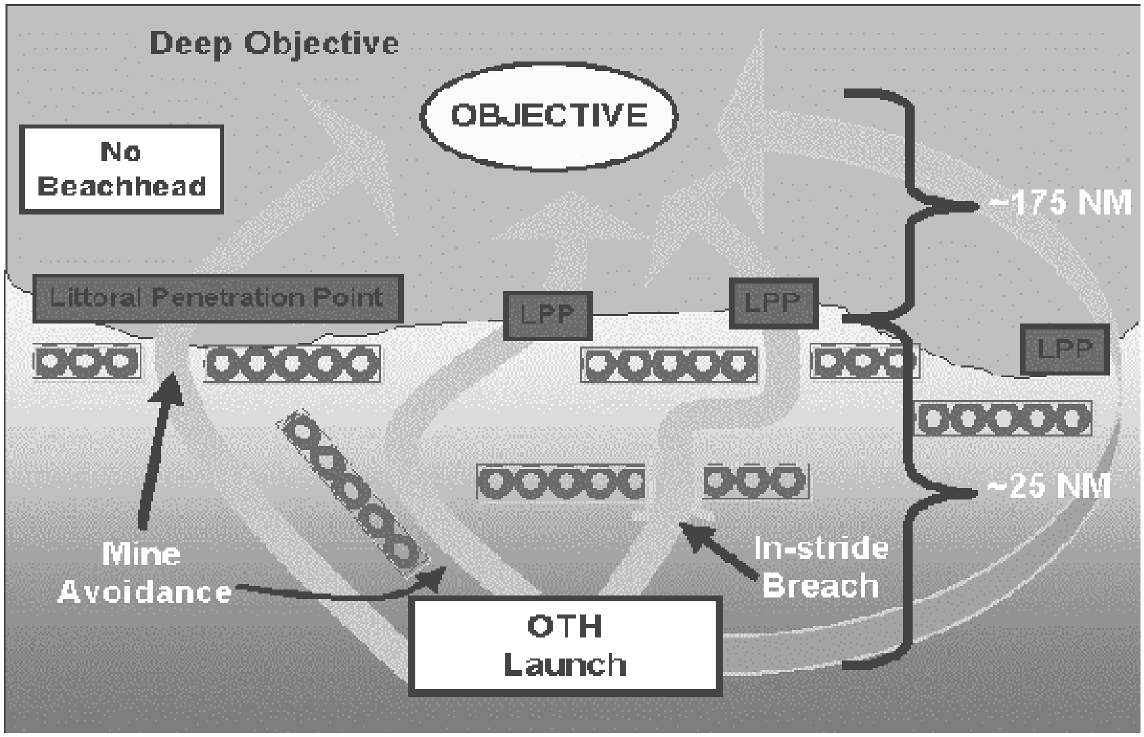

Figure 1. STOM Scheme of Maneuver.

1. Operational Employment Concept

The AAAV(C) will be employed as a tactical echelon command post for ground combat element commanders at the battalion and regimental level. (Figure 2) The AAAV(C) will be employed at the infantry battalion and regimental levels as: (1) a single AAAV(C) functioning as a Tactical Echelon Command Post; (2) two AAAV(C)s divided into Alpha and Bravo command groups functioning as a Tactical Echelon Headquarters; (3) a single/combination of AAAV(C)s combined with other Marine Corps assets to function as a Main Headquarters; and (4), a temporary fire support coordination center (FSCC). It will provide the supported commander and selected staff with the ability to communicate via onboard communications and tactical data systems with senior, adjacent, and subordinate maneuver units, supporting arms units, Combat Service Support (CSS) units, and joint forces, as required. The AAAV(C) will provide all the C2 functionality inherent to Marine Corps Air-Ground Task Force (MAGTF) Command, Control, Communications, Computers and Intelligence (C4I) hardware and software

systems to support infantry regimental and battalion tactical echelon operational requirements. [Ref.1]

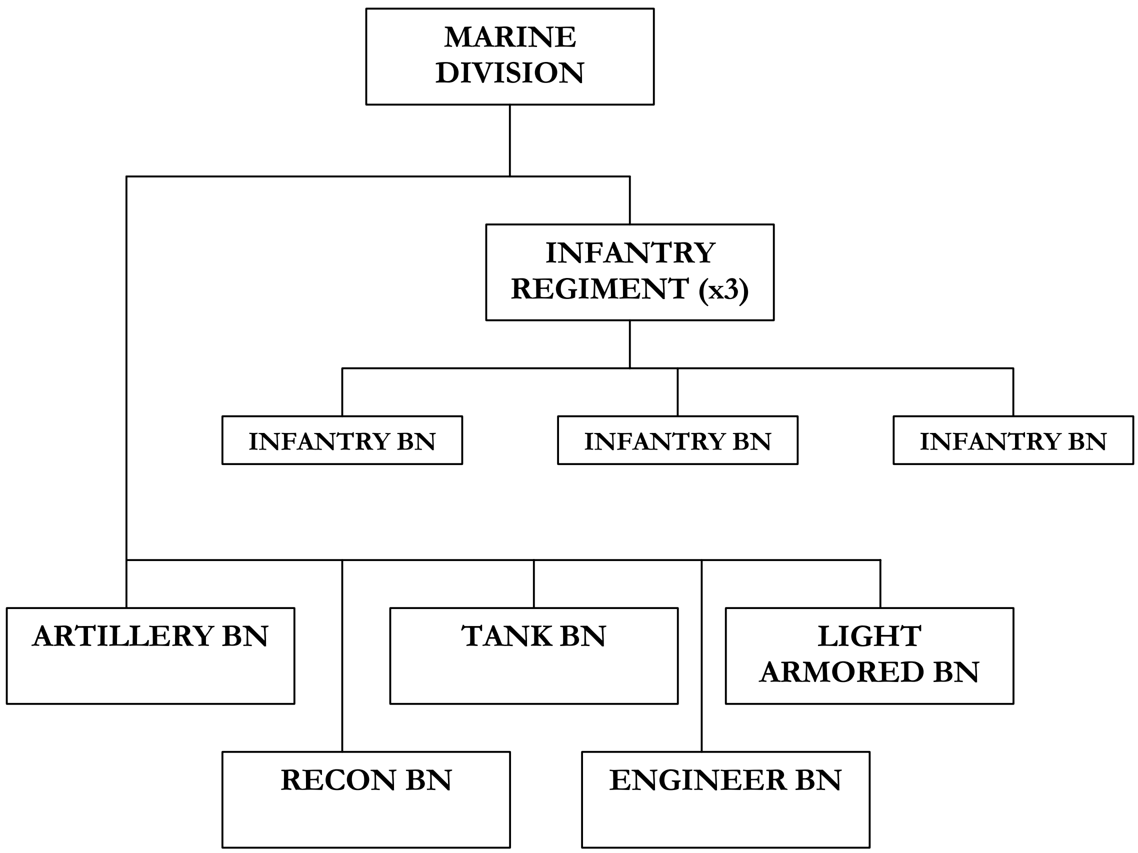

Figure 2. Marine Division Structure.

2. Thesis Origin

The AAAV(C) will provide one of the key command and control platforms and a large part of the communications capability for the first waves of an assault. Due to the distances involved with OTH operations, traditional Very High Frequency (VHF), line-of-sight (LOS) communications will be of limited use. The majority of communications will be conducted over long-range communications networks. Historically these systems have been satellite based or High Frequency (HF) terrestrial radio systems. Because of the current limitations of these systems (availability, cost, bandwidth) their use requires

extensive resource management. Future systems will incorporate emerging technologies such as wireless local area network (WLAN) and will most likely incorporate standard network protocols such as Transfer Control Protocol / Internet Protocol (TCP/IP). Identifying the bandwidth requirements for the vehicle in this environment will enable the Marine Corps to tailor the communications suite to the requirements and help to identify any inherent limitations or factors requiring further study. This topic originated out of discussions with the AAAV program office and the Marine Corps Combat Development Command (MCCDC), Requirements Branch, which followed publication of a study conducted by the Systems Engineering and Integration (SE&I) Division of the Marine Corps Systems Command's C4ISR Directorate. [Ref. 2] General comments from MCCDC personnel concerning this document focused on the need to refine requirements as much as possible and highlighted a lack of data concerning message characteristics (i.e. frequency, size, priority). This deficiency was also noted in the study as a data constraint, specifically, "the frequency of Information Exchange Requirements (IERs) were not available". [Ref. 2] Following these discussions, the AAAV program office requested and provided funding for conducting this thesis research.

B. PURPOSE

The purpose of this thesis is to examine the communications bandwidth requirements for the AAAV(C) given a specific tactical environment. The goal is to identify the optimal bandwidth required to support an infantry battalion tactical command post.

C. SCOPE

The AAAV(C) variant will be primarily deployed as a regimental/battalion, mobile Combat Operations Center (COC). This thesis will focus on the doctrinal network established to support an infantry battalion COC. At the center of this network will be the AAAV(C). All higher and subordinate communications links that connect directly with the AAAV(C) will be modeled. Direct communications between subordinate units will not be modeled. The intent is to identify all traffic received and transmitted through the AAAV(C). Current systems will not be discussed, as this study is intended to be independent of current system characteristics. Notionally this model is based on Internet Protocols (IP), with all communications, including voice and video,

routed via IP addresses. This model will provide much better fidelity for future requirements analysis. Data on message size and transmission interval will allow grouping and analysis of message sets for future systems. Doctrinal messages appropriate for each node (unit) will be identified. Each message will then be assigned a size (bits), and a transmission interval (minutes). Using a specific scenario network traffic flows for a 24 hour period will be modeled with the software simulation tool Extend™. This model will then be optimized in an attempt to identify the minimum bandwidth required to support the scenario.

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II. METHODOLOGY

A. SCENARIO

1. Ship-to Objective Maneuver

Three phases have been identified in a Ship-to-Objective-Maneuver operation. They are ship-to-shore, maneuver ashore and sustained operations ashore. [Ref. 2] To limit the scope of this study a single phase, maneuver ashore, was chosen. Several factors contributed to this choice. First, artillery employment is not a factor until this phase. Doctrinally ship-to-shore maneuver relies on Naval Surface Fire Support (NSFS) until later assault waves have reached the beach and artillery unit positions are established. Using this phase ensures this study will include doctrinal artillery messages. Other inherent characteristics of STOM operations limit the usefulness of the ship-to-shore phase for this study. It is most likely the ship-to-shore phase will be of relatively short duration and occur at night, under constrained radio emissions. This affords a less robust environment to examine bandwidth requirements in a worst-case scenario. The maneuver ashore phase provides a scenario in which the maximum number of network connections is established at the battalion level. It also offers the highest likelihood of prolonged contact with the enemy, supplying the highest levels of transmission activity from fire support and reconnaissance units. The sustained operations phase was not considered because of its similarity to the maneuver phase. The sustained operations phase differs primarily in the addition of network connections with coalition and/or joint forces. Since these connections are usually established at higher echelons than battalion, they will not be examined in this study. Figure 3 provides a general operational view of the units requiring connectivity with an AAAV(C) used as a tactical echelon command post.

Figure 3. AAAV(C) Operational Architecture [From Ref. 3].

2. Assumptions

Many variables exist when attempting to model modern combat operations. A significant variable in many scenarios is the employment of Nuclear, Biological and Chemical (NBC) weapons. In such a scenario NBC reports would be included in the operational message set. These reports were examined for inclusion in this study but information on the operational transmission interval of these messages was difficult to obtain using the experience of Subject Matter Experts (SME's). These weapons have not been used during any recent operations and training scenarios are usually of limited duration and scope. Therefore, the SME's interviewed did not feel they had the experience to speculate on transmission intervals in a high-tempo operational scenario. NBC reports are a part of the Variable Message Format (VMF) message set and as such

are limited in size. Because of this they would probably have a minimal effect on overall bandwidth requirement. However, to properly study their effects would require a separate scenario and study. For this reason NBC reports were not included in this study.

B. NETWORK MODEL

Once an understanding of the general architecture was gained, the individual nodes of a battalion network were modeled. Figure 4 provides a model of a notional battalion.

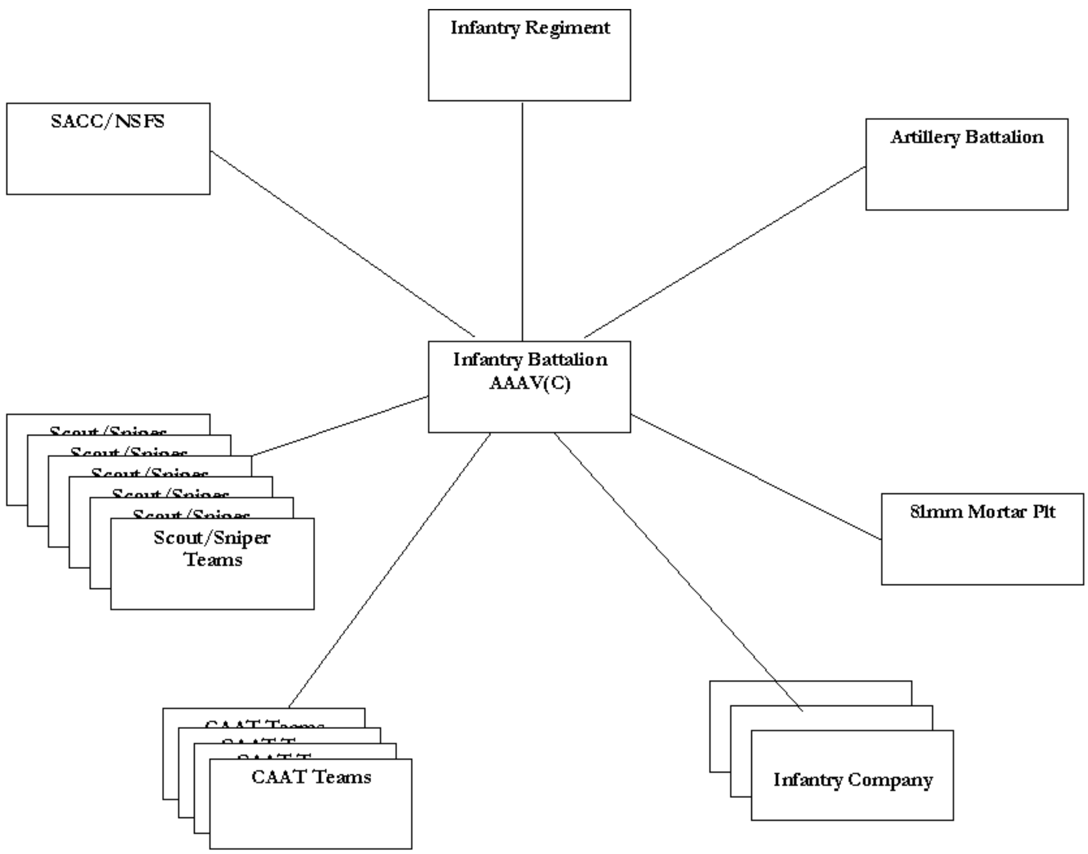

Figure 4. Infantry Battalion Network Nodes.

All units/nodes are doctrinal except for the Combined Arms Anti-tank Teams (CAAT). Comprised of elements from the heavy guns platoon and anti-tank platoon of the infantry battalion's weapons company, these units are mounted on High Mobility Multi-purpose Wheeled Vehicles (HMMWVs). Task organized to provide the infantry battalion commander a screening and reconnaissance force at the battalion level, the use

of this organization, though not doctrinal, is widespread enough to warrant inclusion in the model for this study.

III. DATA

A. DATA SET (APPENDIX A)

The data gathered on message size and transmission intervals is presented in Appendix A. This data is used to populate the tables in the model. The following is an explanation of the data and definitions for each column header in the table.

1. Unit

This denotes the name of each unit as portrayed in Figure 4.

2. Staff Position

This provides destination and origination information one level below the unit level.

3. Msg # (Message Number)

This number is assigned for accounting purposes in the model

4. TX (Transmit)

An "X" in this column denotes that this message originated from a particular Unit and Staff Position.

5. TX# (Transmit Number)

This denotes the number of addressees associated with each message. This is especially important with messages originating from the battalion CP where copies are distributed to all subordinate units.

6. RX (Receive)

An "X" in this column denotes a particular Unit and Staff Position is the recipient of this message. (Note: A message may be both received from a subordinate unit and transmitted. This accounts for higher and subordinate versions of the same type of message.)

7. Message

This provides a short description of the subject message.

8. Size (Bytes)

Message size in bytes (1 byte = 8 bits)

9. Size (bits)

Message size converted to bits. This allows the model to calculate representative bandwidth in kilobits per second (kbps).

10. Transmission Interval

This denotes how often, given the scenario, a particular message will be transmitted by this unit. It is expressed as a function of a 24 hour day or a 60 minute hour. The values expressed in the table were gathered by assembling Subject Matter Expert (SME) opinions. Representatives of each Military Occupational Specialty (MOS) who would occupy the staff positions (S-2, S-3, S-4, FSC, Air Officer) in an AAAV(C) were recruited from the student body at the Naval Postgraduate School to serve as SME's. The representatives were gathered and presented with the scenario outlined above. In an attempt to analyze bandwidth at a peak period, the group was asked to imagine a scenario where the battalion was fully engaged with the enemy and the maximum amount of messages and support requests were being processed. The group agreed the limiting factor in this scenario was a staff's ability to process and act on the information sent. Thus the numbers in this column depict the opinions of SME's on what is the maximum amount of messages that could be processed by an individual sitting at a workstation during high-tempo operations.

B. DATA PRODUCTS

1. Free Text Messages

A key component in analyzing bandwidth is message size. Data on message size was obtained while observing a Digital Command Post Exercise (CPX) conducted by the 2nd Marine Division at Camp Lejeune, NC in May 2001. This exercise created the opportunity to identify and characterize several tactical data products. By far, the most common was free-text e-mail. E-mail provides a flexible, familiar means of communication over tactical networks. By definition, free-text messages are not limited by size; however, Marines are trained early in their careers to be clear and concise when communicating tactically. This translates into most tactical e-mails being limited to a simple paragraph. Over the three days of this exercise, free-text messages ranged in size from 400 to 1024 bytes. By analyzing the "Sent Items" folder at the Division G-3, a good cross-section of message traffic across the Division was observed. The average size

of the 67 e-mail messages received by the Division G-3 was 819 bytes. Thus, for the purpose of modeling free-text messages such as Fragmentary Orders (FragOs) a worst case of 1 KB was used.

2. Formatted Messages

Messages that lend themselves to formatting offer dramatic improvements in processing speed and reduced bandwidth. These messages allow the user to fill in blanks on a standard form. When the user transmits the form only the entered data is sent, not the form data. This greatly reduces message size. A current standard for this type of messaging is Variable Message Format (VMF). Developed by the US Army [Ref 5], it permits an average message size of 300 Bytes. For the purposes of the model this size was used for all formatted messages.

3. Overlay Attachments

E-mail attachments provide a simple means of disseminating supporting overlays and imagery to subordinate units. The size of these attachments is more difficult to quantify because they are dependent on many more variables. Currently map position overlays are built using tactical system applications such as Command Control Personal Computer (C2PC), and then attached to a free-text e-mail. Overlay sizes vary greatly according to map size and number of unit icons used. Observations during the CPX showed only a few examples of overlays. The sizes observed were 61KB and 47KB. These were several versions of an obstacle overlay developed by a combat engineer unit. Conversations with the C2PC program office confirmed these sizes were representative of overlays built at echelons below division level. To ensure a worst-case scenario, 70KB was used as a representative size.

4. Imagery Attachments

Imagery used for intelligence analysis and dissemination is the other file most frequently attached to e-mails. Sizes of images used for this purpose are dependent on several factors. First, original image size depends on the imaging equipment used. Tactical imagery used at lower echelons is commercial digital camera technology. Digital cameras in the common 2.1 mega-pixel range will capture images in a (Joint Photographic Experts Group) JPEG compression scheme to save file space. This will result in an image size of 500-800KB. The level of detail required in the photograph is

dependent on mission requirements. General pictures of tactical objectives can usually be compressed further while maintaining sufficient resolution for on-screen display. With compression level 7, a 800KB picture can be compressed down to 140KB. To ensure a worst-case scenario 140 KB will be used for purposes of the model.

5. Enemy and Friendly Tracks

For real-time situation displays of the Common Tactical Picture (CTP) friendly and enemy position or "track" updates are vital. Tracks are data products that contain basic unit information and position data. C2PC provides track information with an average size of 400 bytes depending on the data fields chosen. Currently tactical systems do not display tracks in real-time. Proposed future systems will provide Global Positioning System (GPS) data for friendly units over real-time datalinks. To model this potential capability and its effect on overall bandwidth a dedicated link is modeled with a data refresh rate of once per second.

6. Voice Links

With the move to data networks many voice messages have moved to a formatted data product. This move helps standardize messages and speed some data processes however, it will not supplant voice communications altogether. Primary voice channels were added to the model using commercial voice-over-IP standards. Conversations with industry provided information on a minimum standard of 16Kbps for acceptable voice quality over IP networks. Ten voice channels were modeled. Seven battalion channels: (1) Tactical (TAC), (2) Intelligence (Intel), (3) Logistics (Log), (4) Artillery Conduct of Fire (COF), (5) 81mm mortar COF, (6) Tactical Air Direction (TAD) and (7) Naval Gun Fire Spot (NGF Spot). Three regimental channels were modeled: (1) Tactical, (2) Intelligence, and (3) Logistics. In this model data products are considered the primary means of communication and voice secondary. Thus, secondary channels (i.e.TAC 2) are not included in this model. Also, local control channels (i.e. Tactical Air Control Party (TACP) are not modeled because they are either monitor-only or not routed through the AAAV(C).

7. Video Links

The primary tactical use of video is for Unmanned Aerial Vehicle (UAV) reconnaissance. One UAV video link was modeled. Commercial industry standards for

video-over-IP were used at 112 Kbps. This allows for a frame rate of 30 frames per second (fps). Using lower frame rates would reduce bandwidth but may produce unacceptable video quality. This link was modeled by adding a constant 112 kbps link refreshed every 1 second over 24 hours.

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IV. MODELING SOFTWARE AND METHODS

A. INTRODUCTION

Currently the Marine Corps Command Operations Centers (COC's) rely on voice communications systems supplemented by a tactical data network which provides basic messaging and Common Tactical Picture (CTP) information. Several tactical data systems are under development but currently none of the existing radio systems are effective data transmitters. The future points to a robust data network with a common architecture. The commercial sector is moving toward this and numerous examples now exist of wireless data networks incorporating voice, messaging, and even video capabilities. These networks run on common protocols allowing for seamless integration of multiple applications. The future difficulty for tactical data networks obviously lies in the development and procurement of high-bandwidth, deployable systems.

Understanding the bandwidth requirements of a battalion COC is a first step in analyzing and measuring Marine Corps tactical data requirements. This understanding becomes imperative for systems such as the AAAV(C) because of their great mobility, compact footprint and internal human factors challenges. Beginning with an understanding of the basic building blocks of message type, message size and transmission interval allows for future C2 system requirements to be examined in detail early in the development cycle. Conducting such analysis with modeling and simulation tools affords the opportunity to quantitatively measure results while mitigating the risks associated with large-scale experimentation.

The use of visual modeling and simulation software in this thesis is intended to explore the information/data requirements in total, and then to, translate them into an understanding of bandwidth for a tactical data system. The software tool inexpensively permits multiple iterations and "what if?" analysis in order to collect and represent data. The choice of a visual modeling tool is intended to permit a more intuitive understanding of the process being modeled and to assist in communicating the method to someone with little or no modeling experience.

Reasons to model and simulate include: 1) Measurement gives an objective basis for decision-making, 2) Systems that are measured are more likely to be improved, 3) Any well thought attempt to measure is superior to not measuring at all. [Ref. 4]

This chapter introduces Extend™, a modeling and simulation software employed to evaluate information flow in business processes. Subsequently, the chapter will decompose the proposed model to explain the relationship between components of the model and the notional network.

B. EXTEND™ VISUAL MODELING AND SIMULATION TOOL

Extend™ is an object-oriented environment for modeling, analyzing, reengineering and documenting processes. It graphically uses icons and links to represent the building blocks of a model in order to facilitate communication between developers and users. Extend™ is designed to permit users to concentrate on the process being examined rather than becoming distracted by modeling methodology or complex software programs.

Extend™ permits the user to develop blocks or icons representing specific aspects of a given system or process. By incorporating the characteristics, activities, queues, delays and transformations that comprise systems, a modeler can assign attributes and values to represent a multitude of various characteristics that would otherwise be difficult to demonstrate. Linking the blocks permits items to flow through their various stages and conditions, and permits quantitative measurements and calculations of the factors to be examined. A variety of graphing options are included to present model output in many formats. The Extend™ libraries include a diverse assortment of pre-configured blocks applicable in many scenarios. Further, Extend™ offers the ability to develop customized blocks for processes or conditions not otherwise covered in the libraries.

C. MODEL PROTOTYPE

Given a message type, size and a transmission interval this prototype will calculate the minimum bandwidth required to allow all messages to be sent and received without significant delay. This will be achieved by imposing a Time Division Multiple Access (TDMA) rule on the handling of messages. This allows each message to use all of the bandwidth some of the time. In other words each message has to wait its turn to

use a single path. In the model this means all messages will be received into a single queue and their delay will be computed as a factor of their size and the available bandwidth. Each node will inject messages into the network at prescribed times.

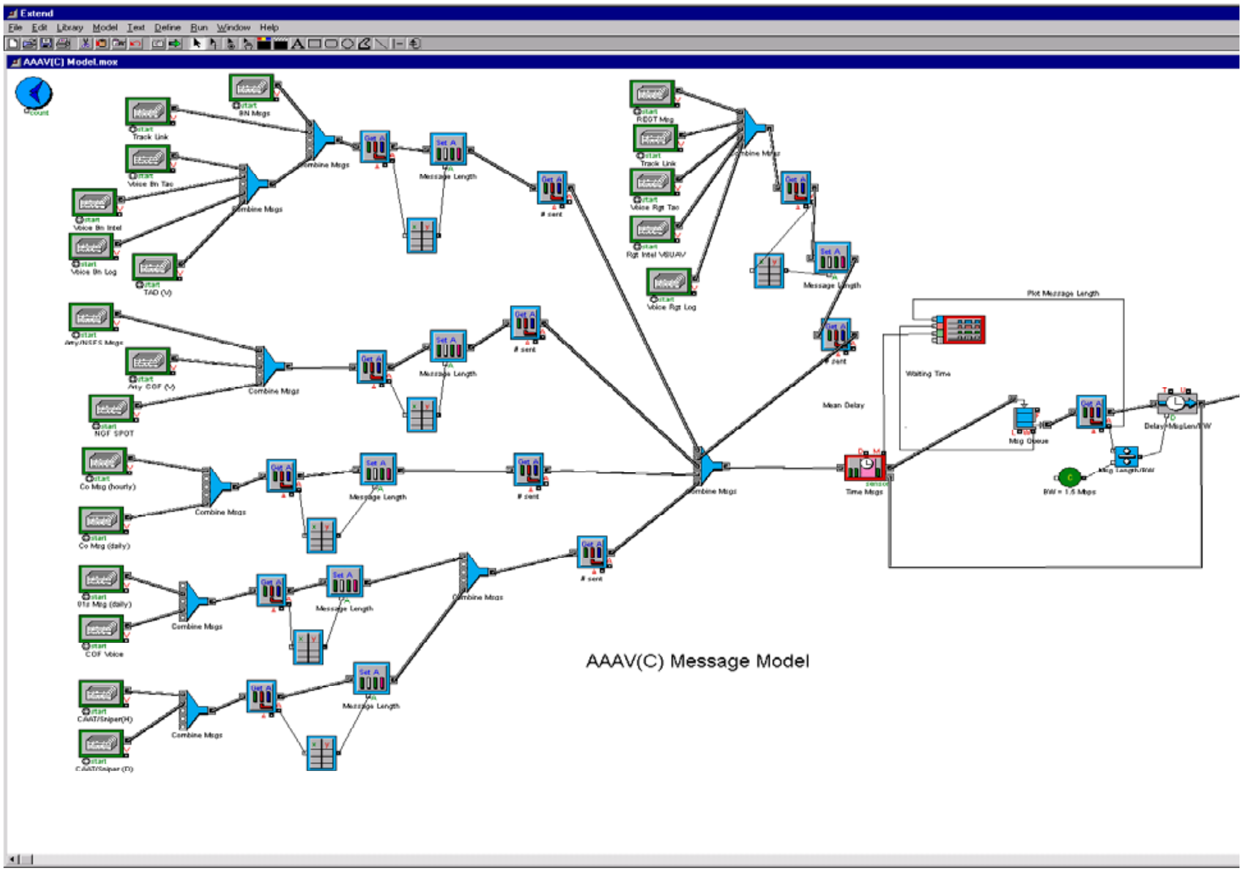

Figure 5. Screenshot of Model.

D. THE MODEL COMPONENTS

Extend™ uses a building block method to graphically depict the components of a system. In order to better understand how each block contributes to the model we will examine each in detail.

1. Executive Block

The Executive Block (Figure 6) is a special block that must be included in all discrete event simulations. It acts as the timer or counter from which other blocks draw information to initiate a sequence of events. In this model, the Executive Block tracks each second in a 24 hour period.

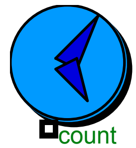

Figure 6. The Executive Block in the Extend™ Prototype.

2. Program Generator

The Program Generator shown in Figure 7 is used to produce items. In the case of this model, each item produced is a message. The Program Generator takes its cue from the Executive Block and generates a message based on output time each time the executive increments the count. Program Generators are used to model message outputs from each network node in Figure 4. Messages from nodes with more than one instance (i.e. Infantry Company X 3) are aggregated into a single program generator. Messages with similar distribution times (daily or hourly) are grouped together into separate program generators to facilitate the appropriate refresh time. Voice and video links are also given their own program generator with refresh rates of 1 second to model the links as dedicated bandwidth.

Within the program generator initial message attributes are set. The attribute "Output Time" is based on the transmission intervals assigned in Appendix A. All output times are in seconds and can be converted to hours. Messages with multiple output times were randomly assigned over the appropriate periods, either daily or hourly. The next attribute assigned is "Message Type" which is assigned from the "Msg #" column in Appendix A. The last attribute assigned in the program generator is "# sent" which is assigned from Appendix A, column TX #.

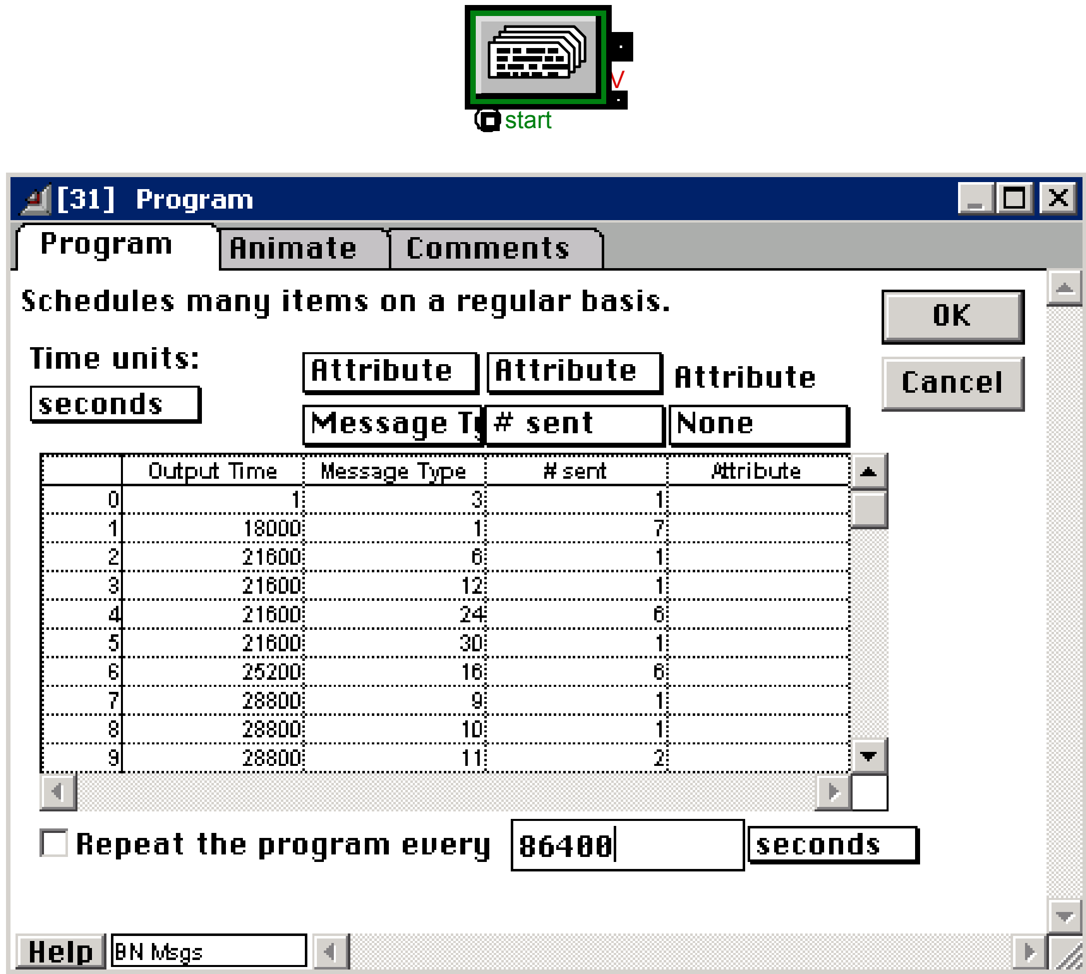

Figure 7. The Program Generator and Dialog Box.

3. Combine Block

Messages flow out of the program generator into a combine block (Figure 6) where they retain their identities but are combined into a single stream.

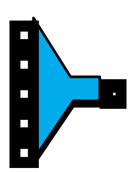

Figure 8. Combine Block.

4. Set Message Size Blocks

After leaving the Combine Block, messages are assigned another attribute "message size", using the Appendix A data from the "size (bits)" column. This attribute is set using a series of blocks that will perform an "if X then Y" operation (Figure 9). "X" being the assigned "msg#" and "Y" being the size in bits. This ensures multiple instances of a message are assigned the same size.

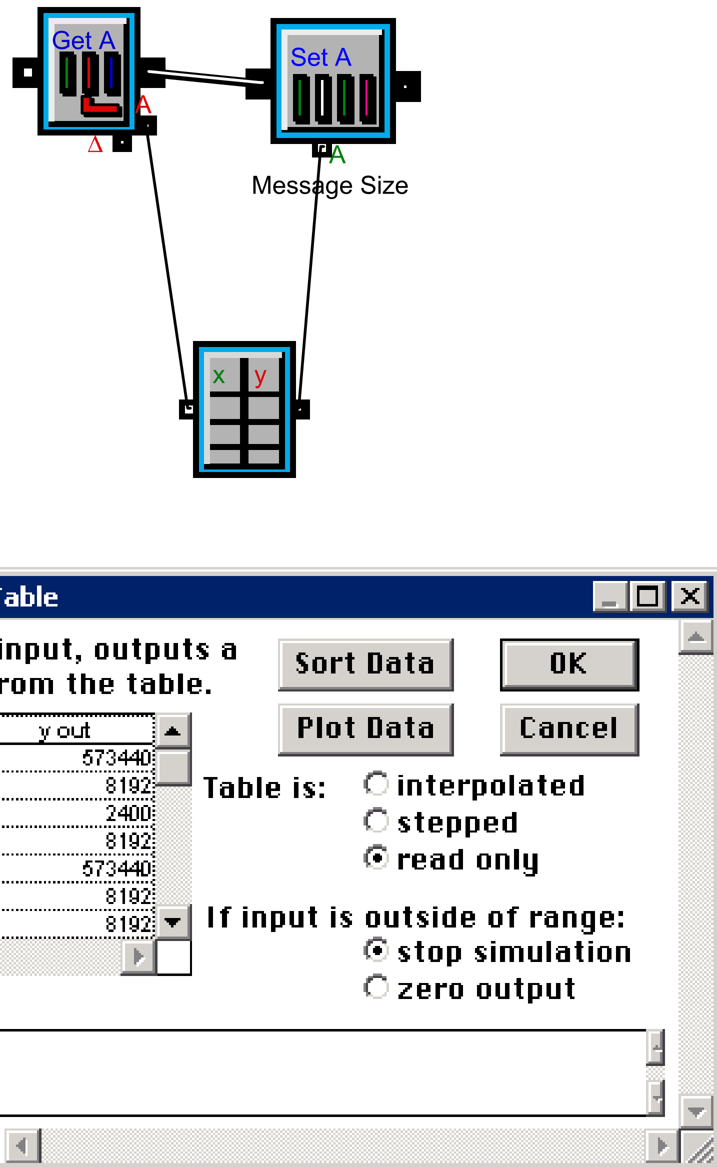

Figure 9. Set "Message Size" Blocks and Dialog Box.

5. # Sent Block

The last attribute set is # sent (Figure 10). Though originally assigned in the program block this action actually multiplies the message by the assigned number. This models the effect of multiple copies or addressees being assigned to the same message.

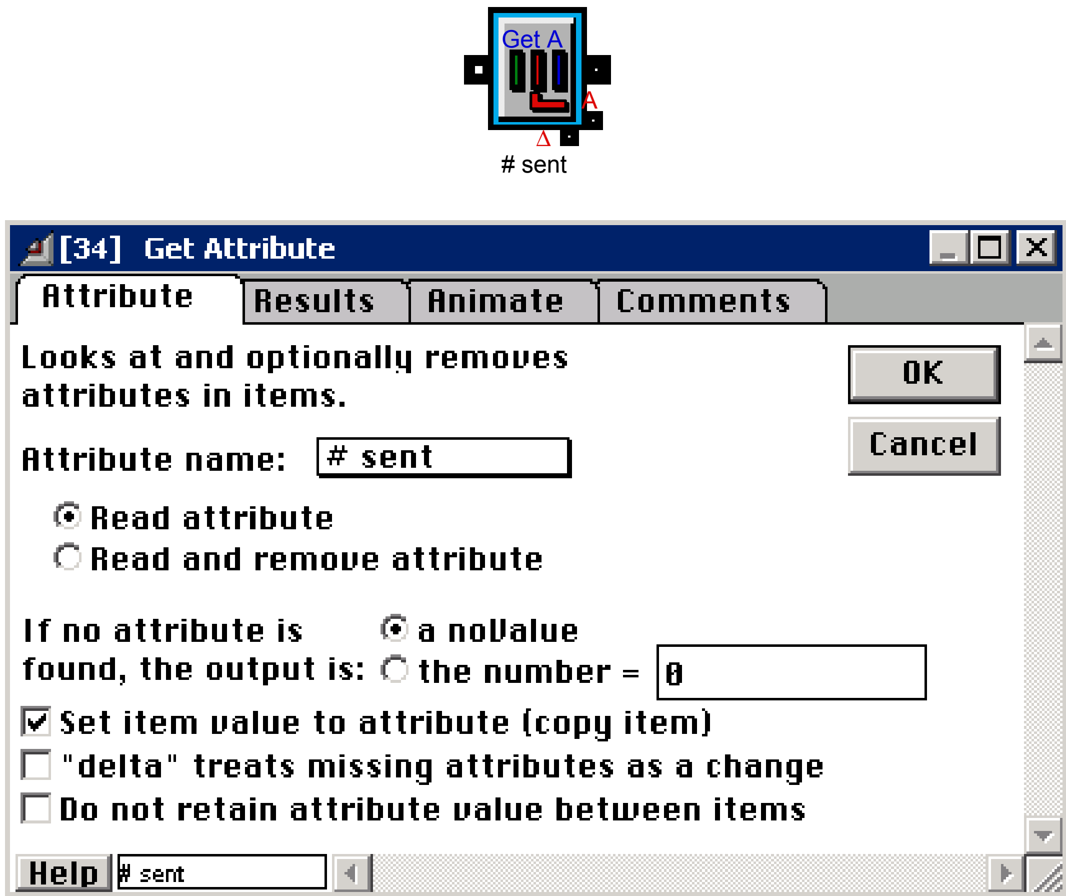

Figure 10. Set Attribute # Sent Block and Dialog Box.

6. Bandwidth Calculator

Following the setting of this final attribute all messages are combined for final processing and bandwidth allocation. During this process each message is assigned a delay as a factor of message size / bandwidth (Figure 11). Sensors are then connected to a plotter to plot "Message Size", "Wait Time" and "Mean Delay" over a 24-hour period.

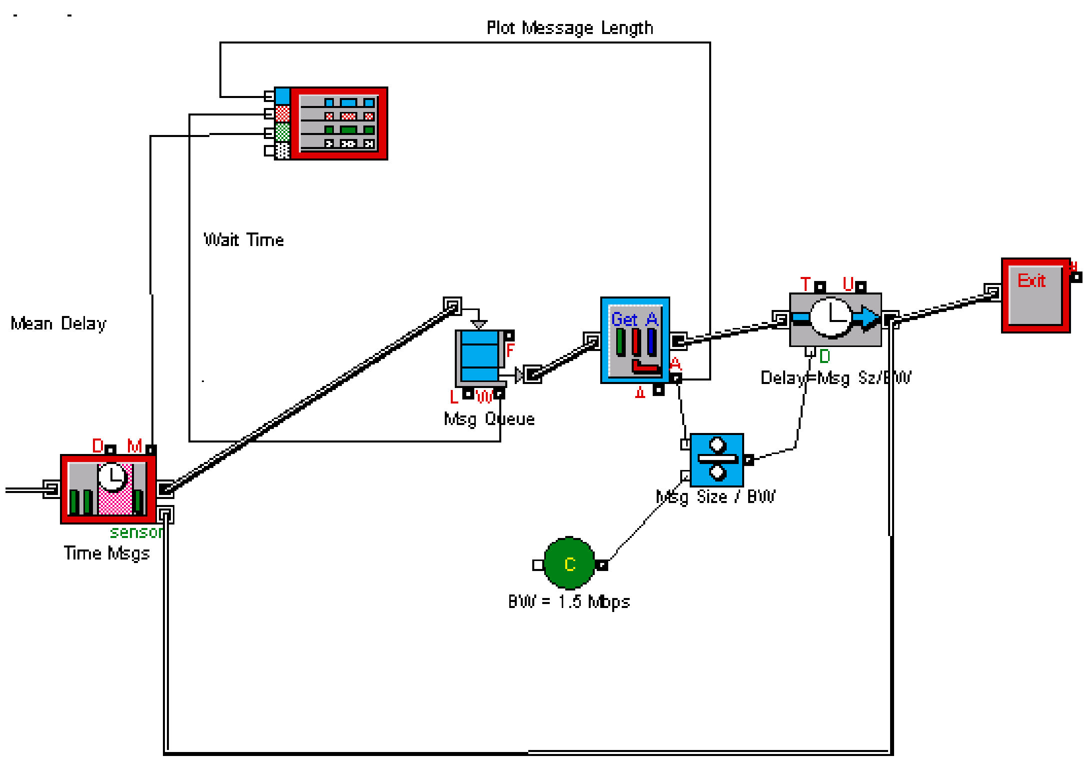

Figure 11. Message Delay Calculator.

The block-by-block description accompanying Figures 4 through 9; is intended to clarify the purpose of the components and methods used in the Extend™ Model. Additionally, the Extend™ modeling tool offers a variety of building blocks applicable to a wide variety of systems. Once a user overcomes the initial learning curve, Extend™ becomes extremely intuitive and user friendly.

V. ANALYSIS OF RESULTS

A. MODEL OUTPUT

1. Results with Voice/Video Links

Voice-over-IP is slowly being implemented and accepted in the commercial sector. It is predicted to eventually supplant dedicated voice networks sometime in the near future. There are many advantages to this kind of network: (1) This allows bandwidth to be used more efficiently because dedicated voice nets no longer sit idle when not in use. (2) Workstation applications can process both data and voice. (3) The establishment and management of multiple narrowband nets is no longer required. The model was first run with all voice and video program generators connected and bandwidth set at 1.544 Mbps. The results are illustrated in the graph generated by the plotter in Figure 12.

The Y1-axis on the left side of the graph displays delay time. The Y2-axis on the right of the graph displays message size. The X-axis provides the time scale displayed in seconds over a 24-hour period. Average delay time was .086 seconds as displayed in Figure 13.

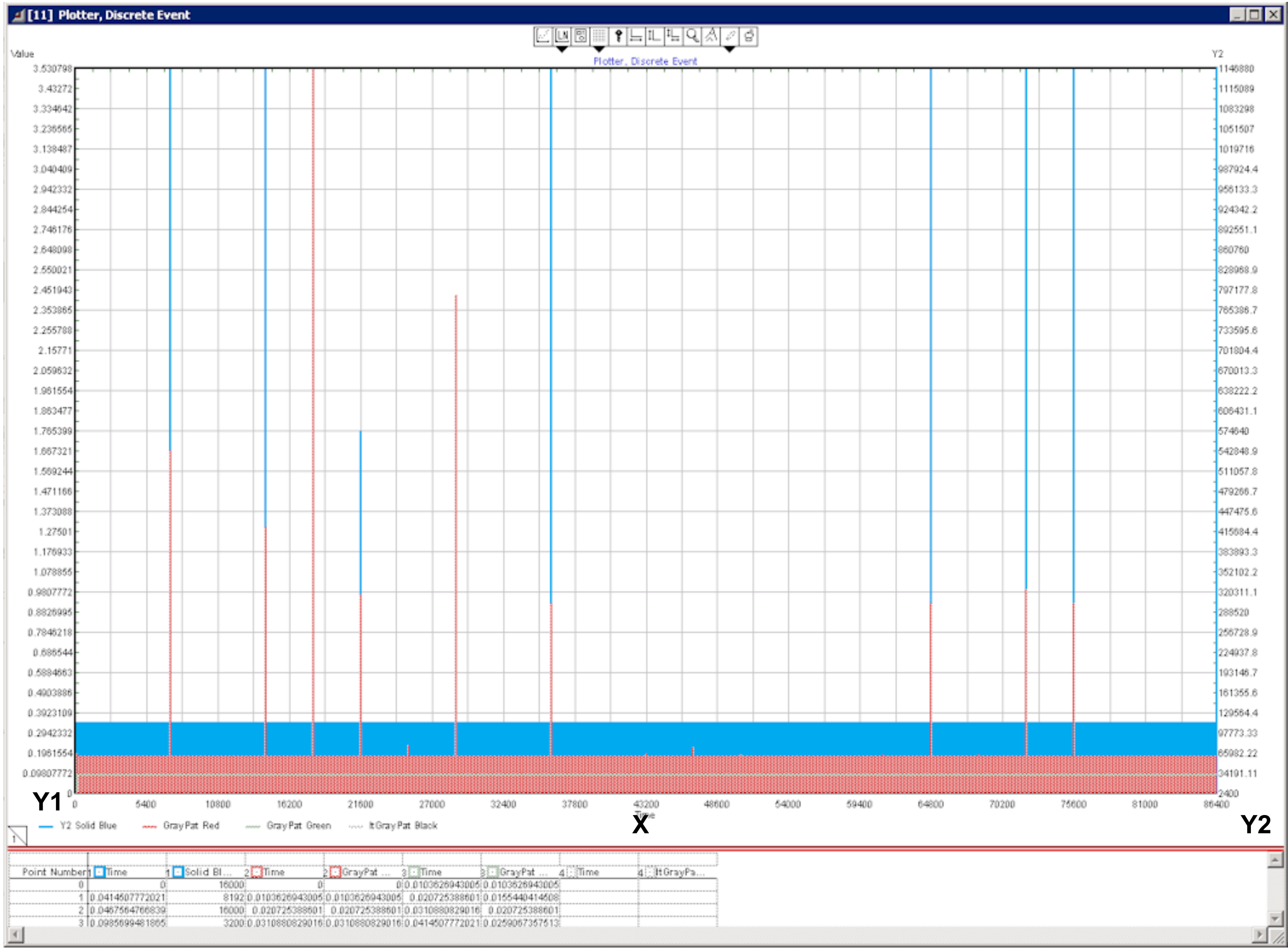

Figure 12. Graph of Results with Voice Links at 1.544 Mbps.

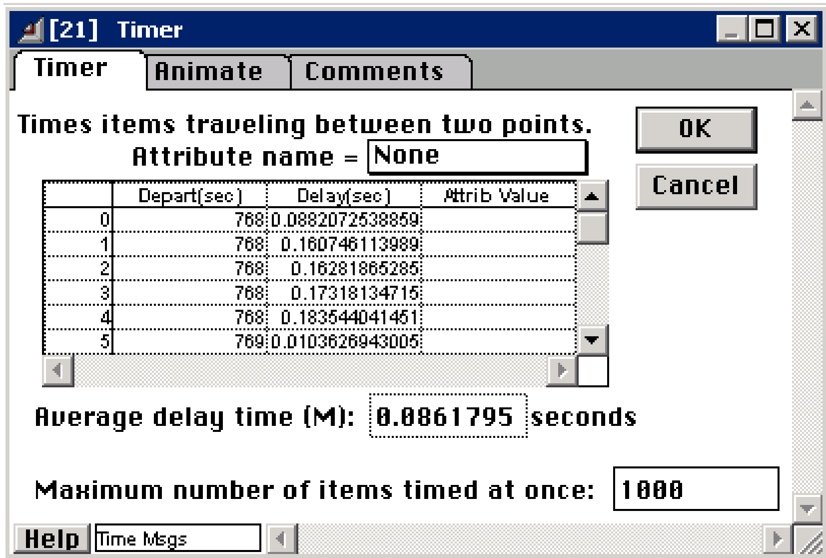

Figure 13. Timer Dialog Box for 1.544Mbps.

2. Results without Voice/Video Links

The model was built with the voice links transmitting a 16 Kilobit message per second. This provides a representation of dedicated voice links transmitting in an always-on mode. Given that voice-over-IP may not be a near term option the model was also run without voice and video links to observe bandwidth effects of only data messages. The bandwidth calculator was set to 512 Kbps. With roughly one-third the bandwidth all data messages are transmitted with almost one half the delay (.045 seconds) of the first iteration. The results show a significant reduction in bandwidth requirements when transmitting only data messages.

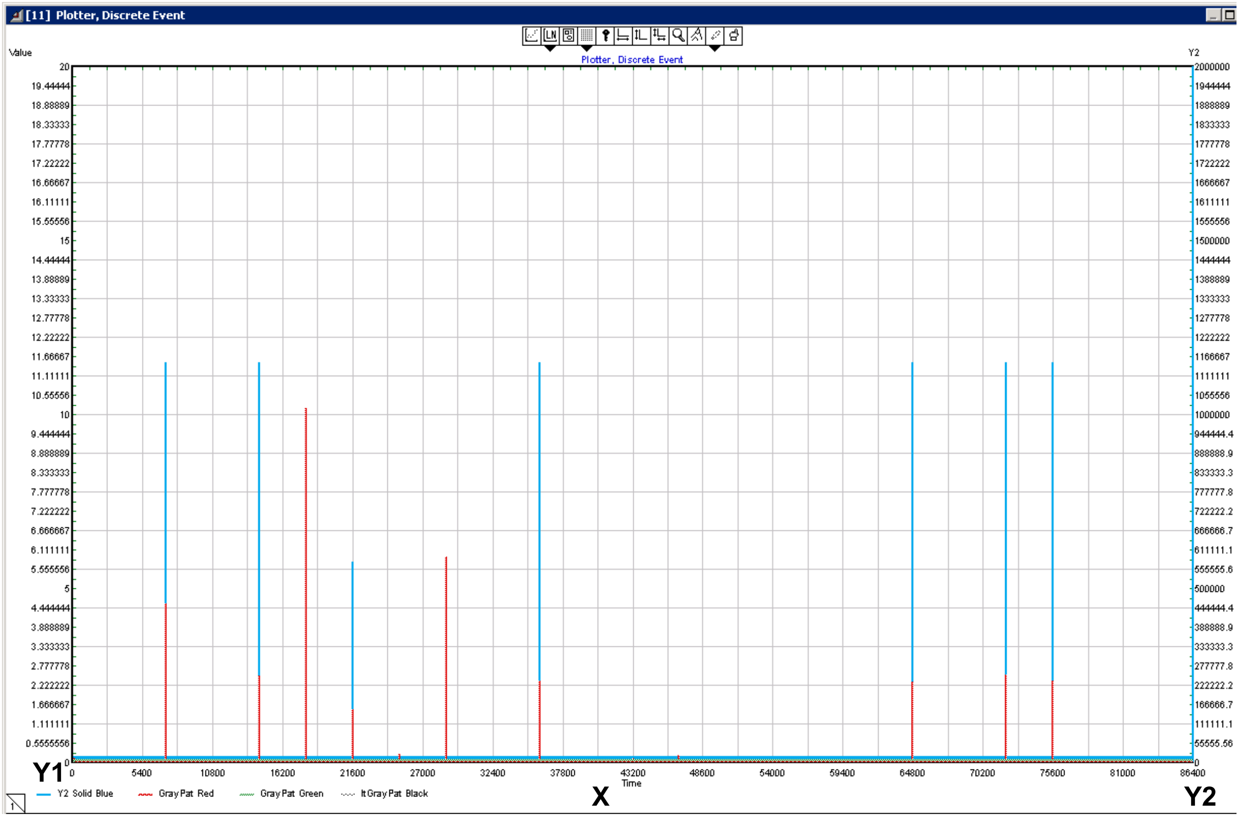

Figure 14. Graph of Results **Without** Voice Links at 512 Kbps.

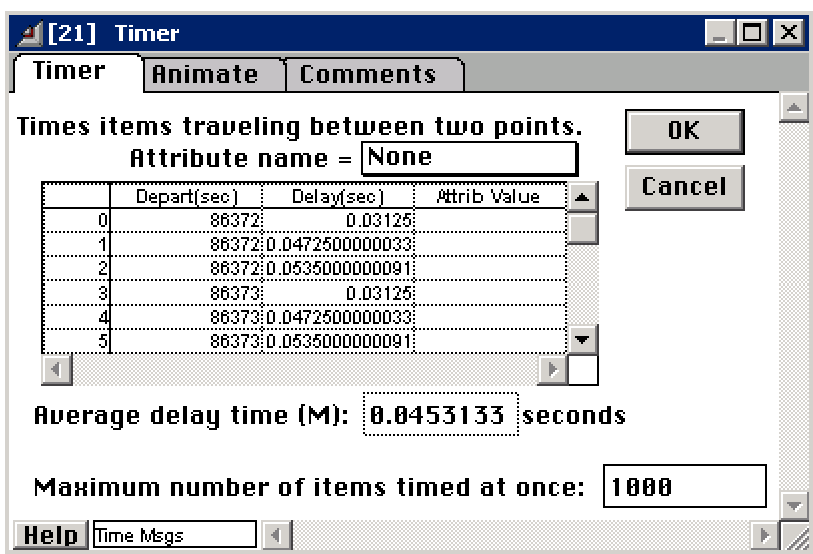

Figure 15. Timer Dialog Box for 512 Kbps.

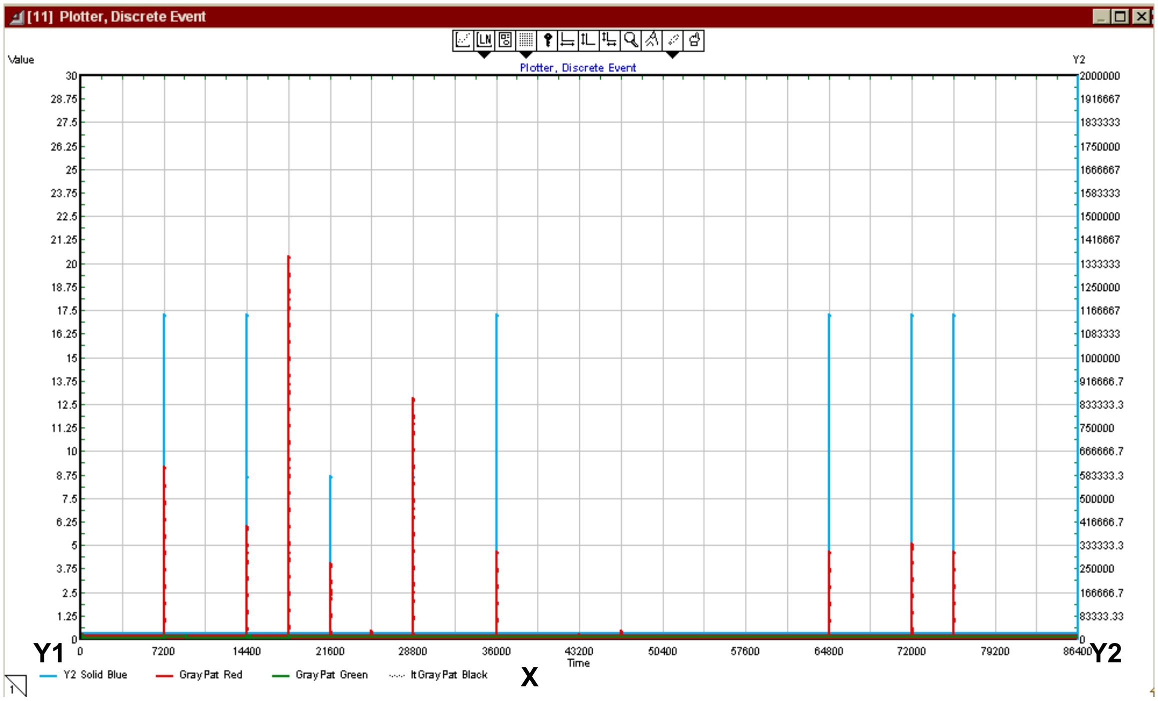

Figure 16. Graph of Results **Without** Voice Links at 256 Kbps.

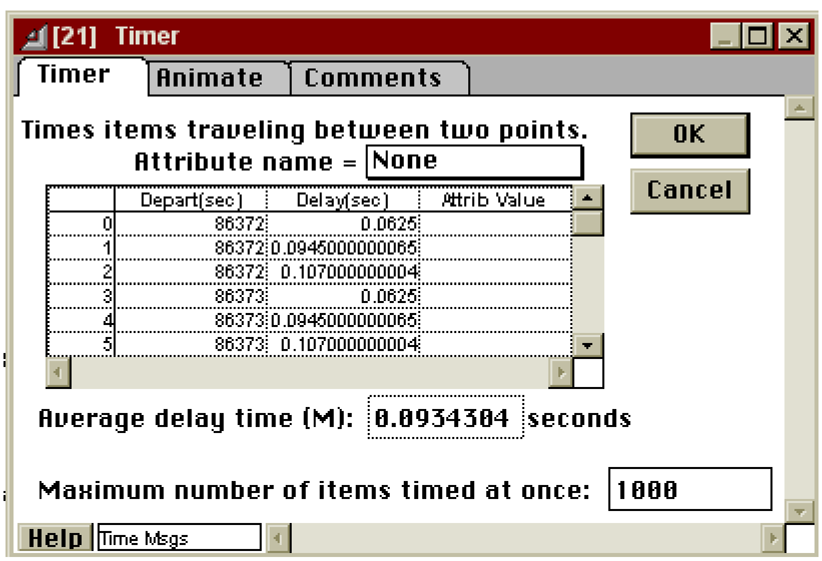

Figure 17. Timer Dialog Box for 256 Kbps.

A "congestion spike" was identified at time, 17924 seconds. This was a result of high traffic volume at a single point in time. This caused the message queue to fill to a point where every message sent during this time incurred a significant increase in delay. The simulation run for 512 Kbps incurred a maximum delay of 3.53 seconds, while the 256 Kbps run incurred a maximum delay of 20.35 seconds. This becomes important as we examine Table 4 in the C4ISP [Ref. 4]. The table assigns timeliness requirements for critical messages. Here, messages have been assigned acceptable delay times based on their priority. Of messages identified in this table, the highest priority messages require a delay of no more than 2 seconds. Neither the 512K run nor the 256K run would meet this requirement if these high priority messages were to be transmitted during this congestion spike. The assignment of message priorities and Quality of Service (QoS) protocols is one way to affect improvements in these delays, but is beyond the scope of this study. A final run was conducted at 2.56 Mbps. This was the minimum bandwidth required to ensure minimum timeliness requirements [Ref. 4] were met. At this bandwidth the maximum delay observed was 2.035 seconds (Figure 18). Following this run, voice/video links were reconnected and the simulation run again with the bandwidth set at 2.56 Mbps. The results of this run show the efficiencies to be gained by the IP communications model. The maximum delay observed during the congestion spike was only 2.19 seconds or a difference of .155 seconds from the previous run.

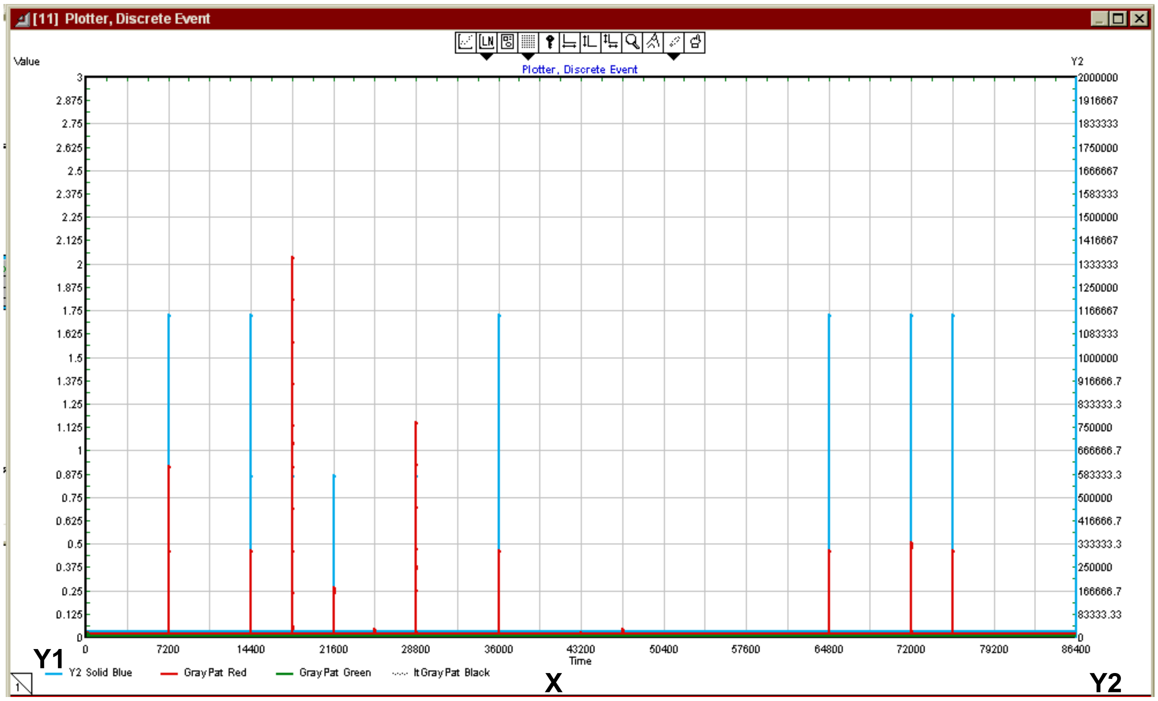

Figure 18. Graph of Results **Without** Voice Links at 2.56 Mbps.

B. PROTOCOL OVERHEAD

This model attempts to be independent of current networks or systems however, it must be pointed out that message size data was gathered from current program sources using current protocols and operating systems. Each protocol adds to the overall system overhead. Overhead is defined as bits added to datagrams to enable delivery or processing within a specified network or system. Increases in overhead are realized as additional protocols such as wireless network protocols are added. This has an immediate impact on message size and consequently decreases network performance. Also, security protocols can add to overhead. Implementation of encryption or Virtual Private Networks (VPN) can have significant impacts on overhead. All of these variables must be considered in detail as requirements for future systems are examined.

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VI. CONCLUSIONS

The AAAV(C) will soon be a centerpiece of the USMC command and control infrastructure. Identifying the bandwidth requirements to support an infantry battalion network is the first step in providing concise, comprehensive requirements documents to support the procurement and development of this and future systems. This thesis addresses one methodology for examining network bandwidth requirements in tactical scenarios.

The STOM, maneuver ashore phase was used as the basis for examining a worst-case scenario for a notional infantry battalion network. An infantry battalion Combat Operations Center aboard an AAAV(C) is modeled and doctrinal messages identified for this network. Data was then collected on the size of each message. A group of Subject Matter Experts (SME's) was assembled and opinions gathered concerning the transmission intervals for each message. This data is assembled and recorded in Appendix A and can provide the basis for future detailed examinations of infantry battalion networks. This data was then used to populate a model created with Extend® modeling and simulation software. Results from this effort show bandwidth requirements for an infantry battalion, tactical COC, without voice/video links or QoS protocols can be met with a AAAV(C) bandwidth of 2.56 Mbps. Including voice/video links only increases the maximum message delay incurred by .0155 seconds.

The current systems aboard the AAAV(C) cannot meet the 2.56 Mbps bandwidth required to accommodate the message traffic identified by the SME's. The bottleneck in the present system is the current reliance on multiple, stove-piped, bandwidth limited systems. What is required in future AAAV(C) variants, in order to meet the message loads identified in this study, are systems at the infantry battalion nodes that can link to a single high bandwidth transceiver that has a minimum bandwidth of 2.56Mbps.

Future tactical communications systems should include the examination of the feasibility of high bandwidth IP based systems. Their efficient use of bandwidth will

provide the most flexibility and growth as data products grow in size and these products are pushed to lower tactical echelons.

APPENDIX A. DATA SET

Unit	Staff Position	Msg #	TX	TX#	RX	Message	Size (Bytes)	Size (bits)	Transmission Interval
Infantry Regt	S-3	1	X	1	X	Op Order/Overlay	70KB	573440	1 per day
		2	X	1	X	FragO	1KB	8192	1 per day
		3			X	SITREP	300B	2400	2 per day
		4	X		X	Friendly Tracks	400B	3200	Constant
	FSC	5	X	1		Target List	1KB	8192	1 per day
		6			X	List of Targets	1KB	8192	1 per day
		7	X	1		FS Overlays	70KB	573440	1 per day
		8	X	1	X	TARBUL	1KB	8192	1 per day
	DASC	9	X	1		ATO	70KB	573440	1 per day
		10			X	JTARS	300B	2400	4 per day
		11			X	Assault Support Requests	300B	2400	3 per day
	S-2	12	X	1		INTSUMS	1KB	8192	2 per day
		13			X	INTREPS	850B	6800	12 per day
		14	X	1		IPB Data/Overlay	70KB	573440	1 per day
		15	X			UAV Video	112Kbps	112000	Constant
		16	X	1	X	IMAGERY	140KB	1146880	6 per day
		17	X		X	Enemy Tracks	400B	3200	Constant
		18	X	1		WX REP	1KB	8192	1 per day
	S-4	19			X	LOGREPS	1KB	8192	1 per day
		20	X	1	X	LOG Overlays	70KB	573440	1 per day
		21			X	LOG Requests	300B	2400	24 per day
		22			X	MEDEVAC	300B	2400	10 per day
		23			X	PERSO Reports	1KB	8192	1 per day
Infantry Bn	S-3	1	X	7	X	Op Order/Overlay	70KB	573440	1 per day
		2	X	7	X	FragO	1KB	8192	2 per day
		3	X	1	X	SITREP	300B	2400	2 per day
		4	X		X	Friendly Tracks	400B	3200	Constant
	FSC	5			X	Target List	1KB	8192	1 per day
		6	X	1		List of Targets	1KB	8192	1 per day
		7			X	ATO	70KB	573440	1 per day
		8	X	7	X	FS Overlays	70KB	573440	2 per day
		9	X	1		TARBUL	1KB	8192	1 per day
		10	X	1		Fire Plan	1KB	8192	1 per day
		11	X	1	X	JTARS	300B	2400	4 per day
		12	X	1	X	Assault Support Requests	300B	2400	3 per day

Unit	Staff Position	Msg #	TX	TX#	RX	Message	Size (Bytes)	Size (bits)	Transmission Interval
		13			X	9-Line Brief	300B	2400	4 per hour
		14			X	Call for Fire	300B	2400	10 per hour
		15			X	End of Mission and Surv	300B	2400	10 per hour
	S-2	16	X	6	X	INTSUMS	1KB	8192	2 per day
		17			X	INTREPS	850B	6800	12 per day
		18	X	6	X	IPB Data/Overlay	70KB	573440	1 per day
		19			X	SPOT/SALUT E REPS	300B	2400	10 per hour
		20			X	OBSTACLE REPORT	300B	2400	6 per day
		21			X	UAV Video		112000	Constant
		22	X	3	X	IMAGERY	140KB	114688 0	4 per hour
		23	X		X	Enemy Tracks	400B	3200	Constant
		24	X	6	X	WX REP	1KB	8192	1 per day
		25	X	1	X	MIJI REPORT	300B	2400	6 per day
	S-4	26	X	1	X	LOGREPS	1KB	8192	1 per day
		27	X	6		LOG Overlays	70KB	573440	1 per day
		28			X	LOG Requests	300B	2400	14 per day
		29			X	MEDEVAC	300B	2400	12 per day
		30	X	1	X	PERSO Reports	1KB	8192	1 per day
Infantry Co	CP	1			X	Op Order / Overlay	70KB	573440	1 per day
		2			X	Frag O	300B	2400	2 per day
		3	X	2		SPOT/SALUT E REP	300B	2400	2 per hour
		4	X	3		SITREP	300B	2400	2 per day
		5	X		X	Friendly Tracks	400B	3200	constant
		6	X	1	X	MIJI REPORT	300B	2400	2 per day
		7	X	1		Log Requests	300B	2400	8 per day
	FO	8	X	1		Call for Fire	300B	2400	6 per hour
		10	X	1		End of Mission and Surv	300B	2400	6 per hour
	FAC	11	X	1		JTAR	300B	2400	2 per day
		12	X	1		Assault Support Requests	300B	2400	3 per day
		13	X	1		9-Line Brief	300B	2400	2 per hour
		14	X	1		MEDEVAC	300B	2400	8 per day
Artiller y Bn	FDC	1			X	Op Order/Overaly	70KB	573440	1 per day
		2			X	FS Overlays	70KB	573440	2 per day
		3			X	Target List	1KB	8192	1 per day
		4			X	TARBUL	1KB	8192	1 per day
		5			X	Fire Plan	1KB	8192	1 per day

Unit	Staff Position	Msg #	TX	TX#	RX	Message	Size (Bytes)	Size (bits)	Transmission Interval
		6			X	INTSUMS	1KB	8192	2 per day
		7	X	1		SITREPS	300B	2400	2 per day
		8	X	1		FIRECAP	300B	2400	3 per day
		9			X	Call for Fire	300B	2400	6 per hour
		10			X	Adjustment	300B	2400	18 per hour
		11			X	End of Mission and Surve	300B	2400	6 per hour
		12	X	1		Ammo Count	1KB	8192	4 per day
SACC / NSFS	LNO	1			X	FS Overlays	70KB	573440	2 per day
		2	X	1		FIRECAP	300B	2400	2 per day
		3			X	Target List	1KB	8192	1 per day
		4			X	Fire Plan	1KB	8192	1 per day
		5			X	Call for Fire	300B	2400	2 per hour
		6			X	Adjustment	300B	2400	6 per hour
		7			X	End of Mission and Surv	300B	2400	2 per hour
81mm Mortar Plt	CP	1			X	Op Order/Overlay	70KB	573440	1 per day
		2			X	FS Overlays	70KB	573440	1 per day
		3	X		X	Friendly Tracks	400B	3200	constant
		4	X	1		SITREP	300B	2400	2 per day
		5	X	1		FIRECAP	300B	2400	3 per day
		6			X	INTSUMS	1KB	8192	2 per day
		7			X	Call for Fire	300B	2400	2 per hour
		8			X	Adjustment	300B	2400	6 per hour
		9			X	End of Mission and Surv	300B	2400	2 per hour
		10	X	1		MEDEVAC	300B	2400	1 per day
		11	X	1		Log Requests	300B	2400	2 per day
CAAT Teams	TM/LDR	1			X	FragO	1KB	8192	1 per day
		2	X	1		SPOT/SALUTE REP	300B	2400	3 per hour
		3	X		X	Friendly Tracks	400B	3200	constant
		4	X	1		SITREP	300B	2400	2 per day
		5	X	1		Log Requests	300B	2400	2 per day
		6	X	1		MIJI Report	300B	2400	2 per day
		7	X	1		Call for Fire	300B	2400	2 per hour
		8	X	6		Adjustment	300B	2400	6 per hour
		9	X	1		End of Mission and Surv	300B	2400	2 per hour
		10	X	1		9-Line Brief	300B	2400	1 per hour
		11	X	1		MEDEVAC	300B	2400	1 per day

Unit	Staff Position	Msg #	TX	TX#	RX	Message	Size (Bytes)	Size (bits)	Transmission Interval
Scout/Sniper Tm	TM LDR	1			X	FragO	1KB	8192	1 per day
		2	X	5		SPOT/SALUTE REP	300B	2400	5 per hour
		3	X		X	Friendly Tracks	400B	3200	constant
		4	X	2		SITREP	300B	2400	2 per day
		5	X	2		Log Requests	300B	2400	2 per day
		6	X	2		MIJI Report	300B	2400	2 per day
		7	X	2		Call for Fire	300B	2400	2 per hour
		8	X	6		Adjustment	300B	2400	6 per hour
		9	X	2		End of Mission and Surv	300B	2400	2 per hour
		10	X	1		9-Line Brief	300B	2400	1 per hour

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